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Adaptation to Climate Change in Coastal Areas and Estuaries

Synthesis report from the meeting of IDRC-funded partners working on climate change adaptation research in coastal areas and estuarine systems

Canada

Adapting to Climate Change in Coastal and Delta Areas in Developing Countries

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Introduction

Coastal areas and estuaries are among the most productive systems on the earth (Adargy et al., 2005). They are responsible for providing important ecosystems services such as 25% of global primary productivity, 90-95% of global fishing production, and 80% of the world's carbonate production (Tolba et al., 1992). Furthermore, coastal areas have a density population nearly three times higher than inland areas, housing a population of more than a billion people, with more than 71% of this population living within 50 km of an estuary (Adargy et al., 2005). Climate change is adding increasing pressure on those areas that are already seriously threatened by human activity.

Several climate drivers influence directly or indirectly coastal and estuarine areas. Among those drivers the most important are flooding, storm intensity and frequency, air and water temperatures changes, precipitation, droughts, sea and lake levels, nutrient levels, salinity, river flow, ocean circulation and mixing (Allison et al., 2009; Brander, 2007; Lehodey et al., 2006). Those drivers have direct and indirect impacts on livelihoods strategies of residents of those areas, especially influencing fishing activities, but also other economic activities, thus compromising their food security (Dulvy et al., 2008, Lehodey et al., 2006, Rosegrant and Cline, 2003). Indeed, more than 90% of fish production is sourced from small-scale fisheries, and 50% of the global fish production is already impacted by climatic changes (FAO Fisheries and Aquaculture Department, 2012). In addition, resident people of estuarine and coastal areas also suffer physical impacts not directly related to their livelihoods, such as diseases and damage on their houses and other infrastructure (Adger et al., 2005; Haines et al., 2006).

Fishing livelihoods, and therefore livelihood portfolios of coastal and estuarine communities that rely heavily on fisheries resources, are useful platforms to study adaptation because those communities are well known for dealing with environmental changes, market uncertainties, and an unpredictable resource base (Coulthard, 2008). However, the main challenge related to detect climate change impacts to coastal and estuarine communities is to distinguish climate-induced changes from changes resulting from environmental and degradation exploitation (Mahon, 2002) as well as changes caused by socioeconomic and developmental factors.

Adaptation is one of the most important responses to climate change, and it is widely recognized by scholars, civil society and policy makers. However, adaptation as a coping strategy, and the challenges of adaptation, are not necessarily new as human have lived with climatic variability for a long-time and developed management decisions to cope with this variability (Dovers, 2009; Smit and Wandel, 2006). Indeed, communities have a long record of adapting to social, ecological and economic changes through a range of practices that include irrigation, crop diversification, water management, disaster risk and coastal zone management, and insurance. Thus, climate change is not the unique driver of adaptation, but it is one

of the contributing factors as demonstrated by examinations of adaptation to multiple stresses (Berrang-Ford et al., 2011; Bunce et al., 2010; Osbahr et al., 2008; Silva et al., 2010).

There is an inherent complexity and heterogeneity related to adaptation to climate change since the adaptation process occurs in the human, social and ecological systems, and thus, adaptation strategies are a result of social, cultural, economic and ecological interaction. Therefore, a *successful adaptation* strategy (Adger et al., 2005) requires a broaden adaptation concept in a way that encompasses the multilevel and the complexity involved on it, such as adjustments that enhance the viability of social and economic activities while reducing vulnerability (Adger et al., 2005, Moser and Ekstrom, 2010, Tompkins et al., 2010).

Scholars and policy makers have recognized that adaptation to climate change takes place through planning development and policy that not only target climate issues or priorities, but also non-climate ones such as urban planning, conservation, and emergency management, which may uphold adaptation to climate change (Dovers, 2009, Smit and Wandel, 2006). However, what we currently know about adaptation is limited. Currently, most of the scientific literature about adaptation to climate change is from developed nations, with few studies from developing countries, and much less from coastal and estuarine areas, which are the most vulnerable ones because the high climatic variability and risks they face coupled with their social and economic limited capacity to adapt (Allison et al., 2009). To fill this gap a workshop on Research for Adaptation to Climate Change in Coastal and Estuarine Systems was organized by the Núcleo de Altos Estudos Amazônicos at the Universidade Federal do Pará and the Climate Change and Water (CCW) Program of the International Development Research Centre (IDRC) of Canada on 2-4 October 2013 in Belém do Pará, Brazil.

This document aims to synthetize some important issues discussed at the workshop with the general literature of adaptation to climate change that need to be taking into account when fostering adaptation to climate change in coastal and estuarine areas. In the following sections, we will present a discussion related to the multilevel complexity involved on adaptation to climate change as well as provide some examples of adaptation strategies taking place on coastal and estuarine areas of developing countries.

Adaptation across scales to climate change on coastal and estuarine areas

Adaptation is a continuous process that involves actions, activities, attitudes and decisions related to all aspects of life and it can be motivated by several factors, such as the improvement of safety or to protect the economic well-being (Adger et al., 2005). Adaptation can be manifested in different ways: by expanding social networks (Adger, 2009) or through market exchanges (Smit et al., 2000). The adaptive capacity of societies and communities can be influenced by physical exposures, social and government institutions, development processes, resource distribution, market changes, and disruption of support networks (Adger et al., 2005; Bassett and Fogelman, 2013; Kalikoski et al., 2010; Smit and Wandel, 2006). It is also linked to governance, flows of capital and labor, dissemination of information and transformations of technologies (O'Brien and Leichenko, 2000, Adger et al., 2005). Thus, individual actions to adapt are not autonomous, but they are constrained by institutional process, such as regulatory structures, social norms and property rights associated to rules in use (Adger et al., 2005).

Other recent studies on perceptions of climate change risks have also demonstrated that stakeholders have ranked poverty and other well-being issues as more important than adaptation to climate change. For example, in Solomon Islands, where local residents rely heavily on fisheries resources for their livelihood, the local perception related to the need to adapt to the risks caused by climate change on this important resource were ranked lower than population increase, social cohesion erosion, land dispute and community conflicts, local economic crisis, and household-level issues such as illness, garden food stolen and household conflicts (Schwarz et al., 2011). Similar results were also found in fishing communities in Mexico (Salas et al. 2010), Mali and Nigeria (Mills et al., 2011). Butler et al. (2013) also found in Indonesia that drivers of changes and vulnerability to climate change are mainly related to development issues as inefficient development investments, local unemployment, and migration labor, fuel and energy prices, food prices, corruption, poor community health and education, and land, water and food availability.

Climate change adaptation needs to be understood at different levels: community, household and individual levels (Coulthard, 2008) but also at different scales: national, regional, and local scales (Adger et al., 2005, Keskitalo, 2010, Termeer et al., 2010, Yates, 2012). Jurisdictional and political levels, and the lower elements involved, could facilitate or constrain appropriate adaptation (Adger et al., 2005, Yates, 2012). Thus, the technology and knowledge available, and the regulatory systems of firms, markets, and municipalities determine adaptation action (Lindseth, 2004, Næss et al., 2005). According to Adger et al. (2005) the success of an adaptation strategy depends on (1) "the scale of implementation" and (2) "the criteria used to evaluate it at each scale". Those two elements are important because adaptation usually involves a cross-scale dynamics with multiples stakeholders and different regulatory systems. To overcome

the complexity of this cross-scale dynamics is important to clearly define adaptation, and its success, by incorporating the spatial and temporal scales (Adger et al., 2005).

Institutional interplay may occur both horizontally, when interactions occur at the same social organization level (different sectors of a municipality incorporate the same adaptation strategies), and vertically, when adaptation strategies are linked to different levels of organization (municipal vs. national levels) (Young, 2002, IDGEC, 2005). However, functional interplay is another important interaction related to climate change adaptation, since few adaptation strategies may address problems that are linked in socioeconomic and biophysical terms (Fidelman et al., 2013).

Climate change adaptation demands a strategic approach that takes into account the interdependency across governance levels while promotes appropriate cross-level interactions (Cash et al., 2006, Termeer et al., 2010). Thus, successful adaptation on climate change in coastal and estuarine areas requires a balance among efficiency, effectiveness, and equity through an institutional structure that promotes appropriate cross-level interactions, which in turn will promote decisions that are perceived as legitimate.

Factors limiting adaptation to climate change in coastal and estuarine areas

Studies carried out in the last decade suggest that adaptation processes and actions face several barriers and limitations (Conde et al., 2007, Moser and Ekstrom, 2010, Pasquini et al., 2013, Islam et al., 2014). These restrictions arise due to the nature of the systems and the characteristics of people involved, and to the context within the systems and people operate (Moser and Ekstrom, 2010), and range from physical and ecological to social and cultural limitations, including also financial and economic, informational and cognitive, and institutional and technological ones. Independent of the type of barriers and limits, they may vary widely depending on the magnitude of climate change, but also on the different groups and their vulnerabilities and adaptive capacity to overcome those limits and barriers.

In terms of financial barriers the main limitation to adaptation seems to be the costs of adaptation, especially in the underdeveloped nations (Conde et al., 2007, Islam et al., 2014). Adaptation to climate change by low-income households and communities are mainly constrained by economic barriers (Conde et al., 2007). Thus, coastal and estuarine communities in developing countries, which rely heavily on fisheries resources and are among the poorest population of the World, have difficulties to adapt to climate change because of the high costs involved on gear repairs, replacement, operation, and increased investments (Mahon, 2002).

Among social and cultural barriers scholars have pointed out knowledge, ethics and values, and risk perception as potential constrains to climate change adaptation (Adger et al., 2009, Conde et al., 2007,

Coulthard, 2008, Nielsen and Reenberg, 2010, Jones and Boyd, 2011, Pasquini et al., 2013). This is the case of the City of Cape Town where poor populations not perceive climate change adaptation as an urgent task when comparing to other basic well being needs such as food security and shelter (Colenbrander et al., 2011; Jourbert et al., 2013). In other cases, cultural barriers can even surpass economics barriers such is the case of Indian artisanal fisheries where the poorest fisherman showed a higher adaptive capacity since they adopted diversification as an adaptation strategy in the opposition of the richest ones, which become locked into a specialized fishery linked to a traditional social regime (Coulthard, 2008).

Informational and cognitive barriers are usually related to interpretation and perceptions of risks. Perception of risks are tightly linked to values and beliefs of individuals, their experiences and knowledge (Grothmann and Patt, 2005, Moser, 2005). Differing perceptions and interests also comprise major barriers to institutional and policy integration (Fidelman et al., 2013). As already pointed out above, in the case of Cape Town conflicts caused by differing interpretations of responsibilities, legislation and policies related to climate change appeared as an important barrier to adaptation (Jourbert et al., 2013). Technological barriers are also documented in the case of coastal communities, where adaptation is constrained mainly because of the lack of appropriate equipment to inform and receive weather forecast, or the high costs of large-scale infrastructure to coastal protection (Ikeme, 2003, Islam et al., 2014).

Vulnerability and adaptive capacity to climate change in coastal and estuarine areas

The same factors that represent barriers and limits to adaptation to climate change such as entitlements, social networks, institutions and governance, technology, economic and natural resources, are also determinants of vulnerability and adaptive capacity of individuals and communities. Indeed, there is a growing recognition that multiple processes of change affect vulnerability and adaptive capacity to climate change (O'Brien and Leichenko, 2000, Turner et al., 2003, Brooks et al., 2005, Luers, 2005, Allison et al., 2009, Bunce et al., 2010, Gómez-Baggethun et al., 2012). Nevertheless, certain factors have been recognized as influencing vulnerability in different socio-political and geographical contexts. Indeed, those factors are developmental elements such those already cited above (elements of governance, health status, inequality, poverty, etc.), and are referred to as generic determinants of vulnerability (Brooks et al., 2005).

In Maldives a study on island communities demonstrated that patterns of development might even exacerbate negative impacts of climate change (Sovacool, 2011). Roads construction, mangrove and beaches vegetation destruction, seawalls building that alter sea nutrient flows, coral reefs dredging and harbors are some activities resulted from development planning that may magnify climate change impacts on this region (Sovacool, 2011). The same trend is also been reported by Florencia Almansi, a researcher with the Impact of

Climate Variability on the Coastal Areas of Argentina and Uruguay in the River Plate Estuary project (106597) supported by IDRC, where territorial development have pressing coastal areas by favoring different high-end real estate developments, encouraged directly by local governments, in an attempt to attract investments in their region. Those real estate activities add pressure on land prices and transform those areas exacerbating potential flood risks, while impacting negatively on the most vulnerable by reducing their access to affordable land. Although modern development patterns are usually the main drivers of change, historic land use practices are also responsible to influence vulnerability of people since land use patterns put people and infrastructure at risk and destroy natural buffers systems. Thus, escalating rates and intensity of changes caused by economic development and land use practices, coupled with other relevant non-climatic drivers, may exacerbate climate change impacts and vulnerability (Armitage and Johnson, 2006, Fazey et al., 2011, Schwarz et al., 2011).

In peri-urban areas of South Asia, urbanization stressors and climate change were also identified as drivers of vulnerability. In those areas vulnerability arises from the lack of access that communities have to alternatives forms of livelihood capital, to water and land, and their inability to organize around institutions (see the IDRC-supported Water Security in Periurban South Asia: Adapting to Climate Change and Urbanization project - 106248). The competition over resources creates conflicts and weakness resilience while increasing vulnerability of those peri-urban communities. Therefore, there is now a global recognition that the capacity to adapt to climate change is inextricably linked to development, and that less developed and poorest regions are more vulnerable to those changes.

When analyzing vulnerability of fisheries communities at the national scale, Allison et al. (2009) found that the most vulnerable fisheries regions identified were Africa, north-western South America, and Asia, and vulnerability in those regions was influenced by the combined effects caused by three main factors: climate exposure, the importance of fisheries to national economies and diets, and the limited capacity of those communities to adapt. Here again, the most vulnerable regions were the poorest. Furthermore, the population of those regions is highly dependent on fish for food and a considerable amount of the fish production in those regions is exported (the most vulnerable countries are responsible for 20% of the global fishery export) (Allison et al., 2009). Thus, if those fisheries communities have not capacity to adapt to climate change, the impact on the global fish production will be considerable, and the most affected people will be first the poorest and most vulnerable.

Another analysis on factors affecting fisheries, and therefore coastal and estuarine communities, and their interaction with climate change, also found that globalization and overexploitation of fisheries makes poor fishers more vulnerable to risks (Daw et al., 2009). Indeed, in Australia several adaptations actions taking place aim primarily to build adaptive capacity by providing information, guidelines and tools to coastal communities, and enabling policy and legislation (Fidelman et al., 2013). A study evaluating adaptive capacity to climate change of artisanal fisheries in Brazil showed that fishing communities “that

diversify and have a higher degree of self-organization" were able to reduce their vulnerability to adverse climate impacts (Kalikoski et al., 2010). Kinship and friendship ties were important mechanisms to minimize uncertainty, and thus, to reduce fishers' vulnerability. This is the case of the study of the Sociocultural Adaptation of Caboclos Communities to Extreme Tidal Events in the Amazon Estuary of Brazil (106711), where household social networks and kinship have been crucial for the rural-urban migration, and consequently, improving those communities to diversify their livelihoods. However, the lack of external institutional support, the disruption of the traditional use of fishing resources, and the recent overexploitation and reduction of fish stocks are important factors increasing the vulnerability of those fishing communities (Kalikoski et al., 2010).

A better understanding of vulnerability and adaptive capacity on adaptation to climate change is possible only with the recognition of the heterogeneity related to vulnerability and adaptive capacity existing among communities (Hahn et al., 2009). By analyzing 29 coastal communities in five western Indian Ocean countries Cinner et al. (2009) provided the most detailed study related to vulnerability sources, and how those sources differ considerably from site to site. These authors also provide useful and detailed policy actions to reduce vulnerability at different temporal and spatial scales. Indeed, in the socio-economically homogeneous communities of the IDRC project Managing the Risk of Flooding and Sea-level Rise in Cape Town: the Power of Collective Governance (105674) it was simpler to create risk consensus, and to reach agreements about how to respond to those risks, than in communities facing inequality and competing needs.

Given that vulnerability to climate risks are context specific, it has spatial and temporal manifestations, which also encompass multi-scalar dimensions (Conde et al., 2007, Wooldridge et al., 2012, Yates, 2012). Thus, many research studies dealing with adaptation to climate change are using multidimensional approaches to understand different sets of conditions and relations. This is the case of the River Plate Estuary project (106597), the Amazon Estuary project (106711), and the Strengthening Livelihood Security and Adaptation to Climate Uncertainty in Chilika Lagoon, India (106703), all supported by IDRC, where vulnerability to flood risks and extreme events impacting coastal communities analyzing socio-ecological, economic, institutional and governance variables. Specifically, in the River Plate Estuary project (106597) climate change hazards have been contrasted to economic loss and taking into account stakeholders' perceptions, and the institutional and governance capacities of municipal governments, to define community resilience. In the case of the Amazon Estuary (106711), vulnerability analysis has incorporated the different household income options, by measuring land and forest products uses, and social pensions accessed by households. Finally, in the Chilika Lagoon project (106703), Participatory Risk Assessment tool, which comprises a broader approach focusing on geophysical, ecological and social contexts of systemic and non-systemic risks, has been used to evaluate communities' risks and resilience (Russi et al., 2013). In those projects the main drivers of vulnerability are the exposure to multiple hazards,

the limited human and institutional capacity, and the lack of articulation between local stakeholders and government levels to climate change risk reduction.

The lack of interaction among local stakeholders and government during the decision making process related to climate change planning is considering one of the most important barriers for adaptation because: 1) it reduced awareness of local stakeholders regarding climate change impacts (Green et al., 2009, Lata and Nunn, 2012), which as a consequence 2) promotes disagreements among policy makers and local stakeholders increasing the changes of policy failure (Patt and Schroter, 2008). Indeed, Patt and Schröter emphasized that simply "telling people that risks are increasing, and that they need to respond in particular ways, simply does not work" (Patt and Schröter 2012, p. 466). Thus, more than providing information, with is a component included on most national adaptation to climate change plans, an active dialog across stakeholders groups in conjunction with their practical involvement on the decision making process of adaptation to climate change is a necessary condition for policy formulation and implementation.

To overcome those barriers discussed above is crucial to integrate the traditional local knowledge in initiatives fostering adaptation to climate change because it can provide successful strategies that have been used by communities to cope with the present climate change impacts. It can also be useful to identify vulnerability stressors, such was the case of the historic land use practices identified in the Cape Town project (105674), which appeared to have a vast influence on increasing risks by putting people and infrastructure at risk and destroying natural buffer systems (Colenbrander et al., 2011; Jourbert et al., 2013). In an attempt to address this issue local knowledge of flooding risks and the local responses to this risk have been traced.

Integrating local knowledge in adaptation plans is important as it contributes to strengthen community adaptive capacity as a result of a greater independence, self-sufficiency, and empowerment (Petheram et al., 2010). Scholars on climate change adaptation have been advocating the implementation of adaptation to climate change plans that link community-level stakeholders and government decision-makers in an attempt to increase the adaptive capacity of communities involved on those plans (Green et al., 2009, Lata and Nunn, 2012, Butler et al., 2013, McNamara and Prasad, 2014). The integration of traditional and informal decision making mechanisms on adaptation plans will be useful especially in coastal and estuarine areas where elected spokespeople and traditional chiefs have a great influence on community members' decisions. In places like that adaptation to climate change will only succeed if a greater voice is given to those leaders and their local decision making mechanisms are incorporated to the climate change adaptation plans (Petheram et al., 2010, Green et al., 2009, Lata and Nunn, 2012).

Adaptation strategies that integrate the traditional local knowledge are also critical to improve the understanding of how biophysical aspects influence vulnerability. For instance, in the case of Chilika Lagoon project (106703) the Vulnerability-Capacity Indicator, the framework that has been used attempts to

integrate the socioeconomic, institutional and environmental elements with the local coping and adaptation strategies that have been adopted (Russi et al., 2013). The same rationality has been also used in the IDRC-supported project on the Impacts of Climate Variability and Climate Change on the Mangrove Ecosystem in Tumbes, Peru (106714), where and effort to understand the local economic activities have been put to improve the understanding of vulnerabilities in the area. Thus, the identification of activities such as shrimp farming and agriculture taking place in the buffer zone, coupled with artisanal extraction of biological resources such as blank conch and mangrove crabs, and tourism that occur on the protection zone, and the analysis of the interrelations among those activities, has been used to define the vulnerability of mangrove systems and the population that rely on this system.

Building adaptive capacity and identifying appropriate adaptation actions requires an initial learning on communities' capacities, knowledge and traditional practices on coping with changes. Moreover, adaptive capacity will be improved if issues such as education, health and governance were addressed, and the nature of actions focusing on those issues was determined by the local contexts.

Improved understanding and communication of adaptation to climate change among scientists, practitioners, policymakers and civil society, are required both within areas in the global south as well as between the global south and north (Ziervogel and Zermoglio, 2009). This understanding and concrete communication is needed to guarantee that support and financing to adaptation to climate change target the right people and communities (Barr et al., 2010, Barrett, 2013). Adaptation finance and support may be allocated to the poorest regions in the world, which are the most vulnerable and less able to adapt to climate change (Barr et al., 2010). To ensure that the right people benefit from adaptation finance, funding agencies need to track how their money is distributed among the most vulnerable regions, and guarantee that funding is allocated in an equitable, transparent and efficient manner (Barr et al., 2010). Indeed, results from a study on Malawi showed that villages that received adaptation finance "address more climate related risks; and enhance agency, security and sustainably lessen climate vulnerability" (Barrett, 2013, p. 1819-1829). Exceptions to this trend exist, however, informal adaptation practices tend to develop short-term strategies with less permanent vulnerability reduction, and address lower proportion of climate risks (Barrett, 2013).

Adaptation strategies to climate change in coastal areas and estuaries

To cope with climate variability, societies have adopted different adaptation strategies such as water management, irrigation, disaster risk management, livelihood diversification, climate forecasting, building infrastructure, and migration. The literature on adaptation to climate change in coastal and estuarine regions of underdevelopment countries is still scarce since most of research on adaptation to climate change has been conducted on developed countries. Most types of adaptation strategies identified

in the projects discussed above were: technological, institutional, changing livelihood strategies, and building adaptive capacity. Those adaptation strategies, and also additional adaptation strategies sourced from the literature, as well the climate changes and impacts that they target are presented in Tables 1, 2, 3.

Table 1. Summary of adaptation strategies adopted on coastal and estuarine areas of developing countries in the Americas.

Country	Climate-related changes	Impacts	Adaptation strategies	Adaptation practices	References
AMERICAS					
Brazil, Estuary of Patos Lagoon	Changes on rainfall related to occurrence of ENSO events	Changes on availability of resources to artisanal fisheries	Livelihood diversification	• Working in industrial fishing and non-fishing works • Varying the species caught	Kalikoski et al. (2010)
			Adjustments related to fishing activities	• Increasing fishing effort with use of high-technology gear (fish-school detection echo-sounders) • Use of more and larger nets, and expanding the variety of fishing gears • Expanding the time spent on fishing and searching and expanding fishing areas • Reducing costs by using cheap materials to boats maintenance, and buying used nets • Use of the traditional fishing calendar when resources are abundant to allow fishers to benefit from the most abundant resources in season • Adding value to the products sold by removing the carapace of shrimp and making fillets of finfish	

			Adjustments to community self-organization and co-management	• Mutual protection of fishing gear, fishing grounds and knowledge sharing about the best fishing spot in a given fishing season • Increasing participation and involvement on decision-making through the Forum of the Patos Lagoon local • Accessing the unemployment benefit program during fishing closures and loans from the National Program for Empowering Small-Scale Agriculture (*Pronaf*) and from the state program *RS Pesca*	
Argentina and Uruguay, River Plate Estuary	Winds and floods variability	Erosion of low-lying land areas, flooding, and damage of buildings and infrastructure	Protection of local infrastructure	• Modifying plot levels and housing characteristics	IDRC-CDRI (2014a) IDRC-CRDI (2014b)
			Institutional strategies	• Fostering working collaborations between communities and local government • Increasing knowledge and designing adaptation policies and risk management scenarios	

Brazil, Amazon River Estuary	Tidal floods risks	Compromising agriculture production and damage of local infrastructure	Livelihood diversification	• Increasing engagement on forest, aquatic, and agroforest resources than in agriculture products • Assessing the federal government subsidy "Hunger Zero" Program (Programa Fome Zero) • Labour migration to urban areas	Pereira (2014)
			Housing strategies	• Dwelling changes	

Table 2. Summary of adaptation strategies adopted on coastal and estuarine areas of developing countries in Asia.

Country	Climate-related changes	Impacts	Adaptation strategies	Adaptation practices	References
ASIA					
India, Publicat Lagoon (South India)	Environmental shocks through natural events such as cyclones and anthropogenic events such as pollution; Inconsistent monsoon rainfall and lack of fresh water run-off, resulting on water salinity and temperature increase.	Changes on availability of resources to artisanal fisheries.	Livelihood diversification	• Engage with non-fishing livelihoods • Supplementing the Padu system fishing, which allow fishers to fish once in 12 days using larger nets, with the use of small-scale and inexpensive fishing gears, unregulated by Padu system, outside their Padu fishing day	Coulthard (2008)
India, Chilika Lagoon	Variability of water flow within the basin, and flood risks.	Compromising maintenance of hydrological regimes and the balance between coastal and freshwater hydrological processes, threatening	Institutional strategies	• Generating risk reduction plans with community participation • Formation of the Village Level Disaster Resilience Committees (VLDRC) • Improving understanding of vulnerabilities within coastal communities • Training of VLDRC members on improving natural infrastructure,	IDRC-CDRI (2014a) IDRC-CRDI (2014b)

		livelihood security		strengthening and diversifying livelihoods and disaster preparedness	
China, Yellow River	Increase in frequency and duration of "no flow" events.	Water shortages affecting agriculture irrigation and threatening farmers' livelihoods.	Livelihood diversification	• Diversifying agriculture production by investing on greenhouse vegetables and winter date	Liu et al. (2008)
			Production specialization	• Investing on livestock husbandry • Investing in date business	
			Water use reduction	• Drought resistant varieties • Plots clustering • Increasing cotton sown area • Decreasing wheat sown area	
			Increasing water supply	• Building reservoir • Drilling wells • Dredging canals	
			Simply coping	• Adopting selective irrigation	

			Engaging on community activities	• Attending date and livestock fairs, and joining the pig club or greenhouse club, which improved access to markets and technological information • Increasing access to bank loans through village councils	
Philippines	Drought and floods	Water shortages affecting crop production	Increasing water supply	• Using shallow tubes • Construction of water impounding basin	Lasco et al. (2006)
		Soil degradation	Water use reduction	• Adopting a rotation method of irrigation during water shortage	
			Adjustments related to crop production	• Adopting silvicultural soil treatment schedules to suit climate variability • Shift to drought-resistant crops	
			Soil protection	• Construction of fire lines and controlled burning	
			Investing on conservation strategies	• Adopting of soil and water conservation measures for upland farming	
Bangladesh	Sea-level rise and saltwater intrusion	Coastal erosion and water shortages	Coastal protection	• Building of flow regulators in coastal embankments	Agrawala et al. (2003) Pouliotte et al. (2006)
			Increasing access to water	• Investing on low-technology water filters	
			Adjustments related to crop production	• Adoption of alternative crops	
South Asia, New Delhi	Water stress, and increasing salinity on groundwater	Decrease in water availability	Using new technologies to access, store and distribute water	• Harvesting rain water • Building dikes around agricultural plots to store water	IDRC-CDRI (2014a)

and Hyderabad (India), Katmandu (Nepal), and Kulna (Bangladesh)		threatening livelihoods	Creating institutional arrangements to allocate, distribute, and share water, and to foster collective action	• Installation of community tube wells and collectively taking ponds on lease for drinking water storage	IDRC-CRDI (2014b)
			Livelihood diversification	• Altering water use practices shifts in crops and cropping patterns or choices, altering settlements patterns, and short and long migration	

Table 3. Summary of adaptation strategies adopted on coastal and estuarine areas of developing countries in Africa.

Country	Climate-related changes	Impacts	Adaptation strategies	Adaptation practices	References
AFRICA					
Burkina Faso, Sahelian zone	Drought, flooding and increase of winds intensity and frequency.	Compromising rain fed agriculture	Livelihood diversification	• Labour migration to Côte d'Ivoire • Working on development projects • Investing on gardens that are supplied by small wells (which are independent of rainfall variability and drought) for cash crops like potatoes, tomatoes, onion and watermelon • Increase of women's work to improve household income	Nielsen and Reenberg (2010)
Egypt	Sea-level rise	Coastal erosion	Coastal protection	• Installation of hard structures in vulnerable areas to coastal erosion • Project approval and regulation setback distances to coastal infrastructure	El Raey (2004)
Sudan	Drought	Water shortages	Increasing water supply	• Expanding the use of traditional rainwater harvesting and water conserving techniques	Osman-Elasha et al. (2006)

			Increasing the efficiency of rangelands and animals grazing practices	• Building of shelter-belts and wind-breaks to improve resilience on rangelands • Monitoring the number of grazing animals and cut trees	
Botswana	Drought	Compromising crop production	Building adaptive capacity	• Investing on adaptive capacity of local authorities • Providing assistance to small subsistence farmers to increase crop production; • Creating employment options after drought	FAO Subregional Office for Southern and East Africa Harare (2004)
South Africa, Cape Town	Sea-level rise, increase of rainfall, more intense storms, increase in seasonal and annual temperature, salinity intrusion, changes in humidity and evaporation.	Flooding compromising agriculture, and immigration from rural areas with increasing of informal settlements	Building adaptive capacity	• Assisting on the identification and distinction between public and private (household) responsibilities in the governance of terrestrial flooding risks • Improving effective collaboration and improving the understanding of vulnerabilities/adaptation by shifting from a reactive (disaster relief) to a proactive (spatial planning, early warning) approach to flood management	IDRC-CRDI (2014a) IDRC-CRDI (2014b)

			Strengthening governance	• Facilitating the process of interpretations of national legislation and perceptions of what ought to happen, and who should be held responsible, between local, provincial and national government	

Conclusion

As discussed in this paper, adaptation to climate change is a complex, heterogeneous and dynamic process. The adaptation process encompasses multi-scalar dimensions, which involve not only climate-related factors, but also socioeconomic, institutional and governance issues. Similarly, vulnerability to climate change is also influenced by the degree to which biological, geophysical and socioeconomic systems are susceptible to, as well as unable to, adapt with the adverse and negative impacts of climate change. Thus, addressing vulnerability to climate change in coastal and estuarine areas means to include the physical and ecological features related to those ecosystems as well as their social, cultural and economic contexts.

Results of recent studies on adaptation to climate change demonstrate that there is an overlap between vulnerability and adaptive capacity to climate change and development pathways and poverty. Thus, beyond the higher degree of climate susceptibility related to coastal and estuarine areas, there is also a high level of vulnerability in those areas as a consequence of the inextricable effects of development pressure on those areas, coupled with their poorest population. In terms of the social, political and economic contexts of coastal and estuarine areas of developing countries it is important that scholars, policy makers and financing agents focus to ensure the implementation of successful adaptation measures. The lack of research and literature on less developed and poorest regions coupled with the lack of procedures to determine vulnerability drivers and the identification of adaptation strategies at the local level, prove to be a challenge for adaptation to climate change to succeed in the most vulnerable regions, which come to be the coastal areas of the least developed countries. However, the issues related to research projects described in this article demonstrated the importance to identify and analyze socioeconomic and ecological variables, as well the cross scale interactions related to climate change, to improve the understanding of vulnerabilities in coastal and estuarine areas of developing countries. Results from those projects acknowledge tacitly or explicitly, and at different levels, the interchangeable socio-ecological and developmental characteristics related to the vulnerability of coastal and estuarine areas to climate change. Therefore, those studies highlight that climate variability and climate change are only two factors among several direct and indirect factors determining vulnerability and adaptive capacity, which make necessary the integration of climate change adaptation needs to development pathways and issues such as poverty.

In relation to the different governance levels involved on adaptation to climate change, research on multilevel adaptation is still scarce (Urwin and Jordan, 2008, Juhola and Westerhoff, 2011, Keskitalo, 2010, Termeer et al., 2011, Westerhoff et al., 2011. There is a prevalence of research focusing on a single-level of governance, especially at the national level. Thus, future research need to address the cross-scale interactions among different stakeholders, mainly how government strategies constrain or support

adaptation of industries and communities. How institutional responses to climate change affect communities vulnerability, and which institutions facilitate or constrain adaptive capacity of these communities.

However, even though variability is inherent to coastal and estuarine areas their communities and ecological systems are also well prepared to undertake effective adaptations strategies, adaptation strategies targeting climate change in those areas may fail if policies that regulate development matters continue to neglect (1) the resilience of coastal ecosystems, (2) their socioeconomic and cultural contexts, (3) the different levels of interactions among stakeholders, and (4) their capacity to adapt to climate change. Models and scenarios are important tools for the integration of the multilevel and complexity involved on adaptation to climate change. They can serve as guides to define governmental and societal investments to overcome the climate change impacts they face, but also track changing priorities over time, and thus, integrate the temporal dimensions of climate change, and guarantee the success of the adaptation strategies adopted in the long-term.

In addition, climate change adaptation in coastal and estuarine areas must not to be only a matter of researchers and policy makers, but also involve the local beneficiaries of adaptation to climate change, and their traditional knowledge and institutional mechanisms, by favoring an active dialog among all stakeholders, and their practical involvement on the decision making process involved on adaptation to climate change. The current literature on adaptation to climate change has focused on the regional, national or global levels. So it become evident the need of research that focus on adaptation to climate change at the local level. Researchers need to understand how adaptation to climate change is negotiated among local stakeholders, especially at the individual and household levels (Coulthard, 2008).

Policy makers, scholars, entrepreneurs and community leaders of coastal and estuarine areas must be part of the process of identifying vulnerability drivers as well as potential adaptation strategies to be adopted locally. For this, is extremely important to take into account the differing perceptions related to climate change among the stakeholders involved in those areas, and thus, prevent negative reactions or conflicts that may be added to the already high vulnerability to adaptation to climate change in those areas.

Finally, the lack of research and literature at the local level of adaptation to climate change in coastal and estuarine areas of developing countries represent a challenge when dealing with understanding vulnerability and adaptive capacity, and in identifying adaptation strategies in those regions. However, it must not be a reason for inaction. We provided several examples of research taking place in those areas, and how those results have been proved to be extremely useful on the improvement of adaptation to climate change knowledge. Indeed, coastal and estuarine areas can be used as case studies to test strategies of adaptation to climate change not only in coastal and estuarine areas, but in other regions of developing countries.

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